Search for direct CP violation in neutral charm mesons decays

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on behalf of the LHCb collaboration

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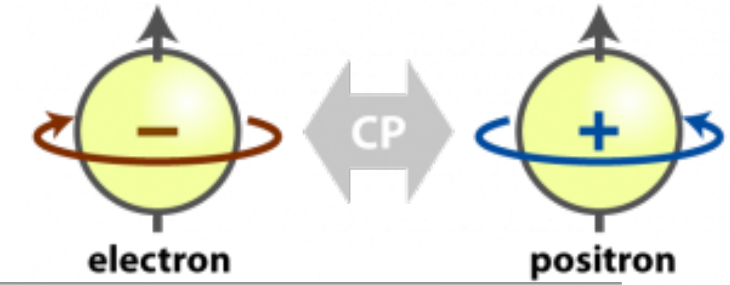
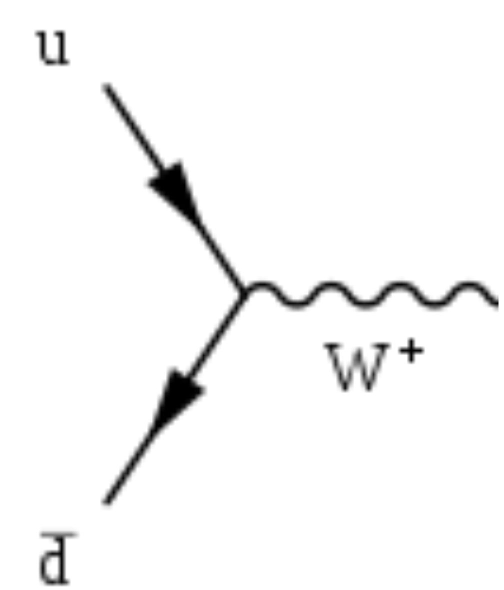
CP violation

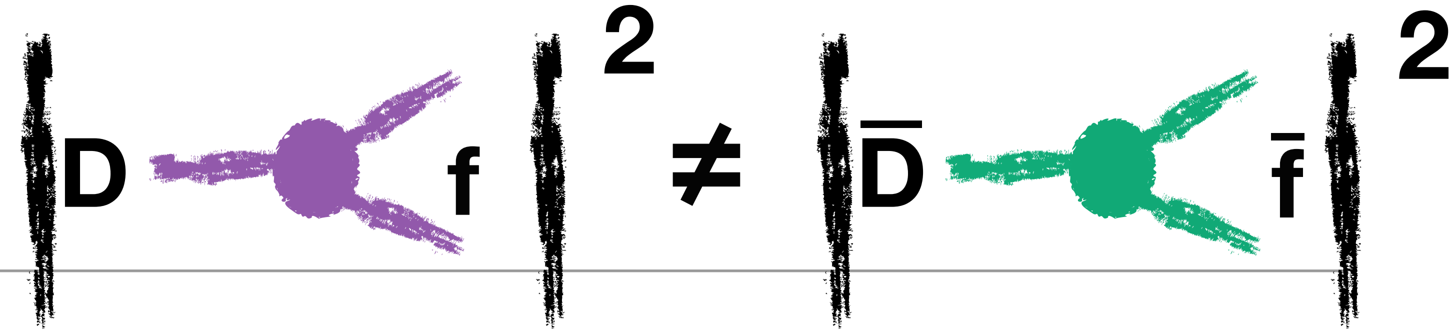


- ***CP*** is the combination of the charge conjugation *C* and parity transformation *P*
- If there is a difference between the ways nature treats ***matter*** and ***antimatter*** then *CP* is violated
- Within the Standard Model (SM), *CP* is naturally violated in weak *charged-current* interactions of *quarks* because of the complex phase in the **CKM matrix**

$$-\mathcal{L}_{W^\pm} = \frac{g}{\sqrt{2}} \begin{pmatrix} \overline{u} & \overline{c} & \overline{t} \end{pmatrix} \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix} \gamma^\mu W_\mu^+ + h.c.$$



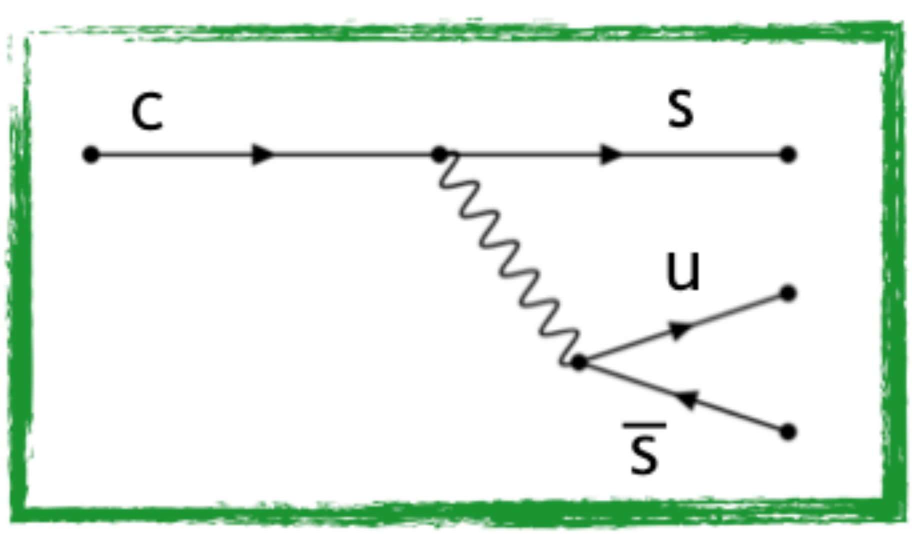
Direct *CP* violation



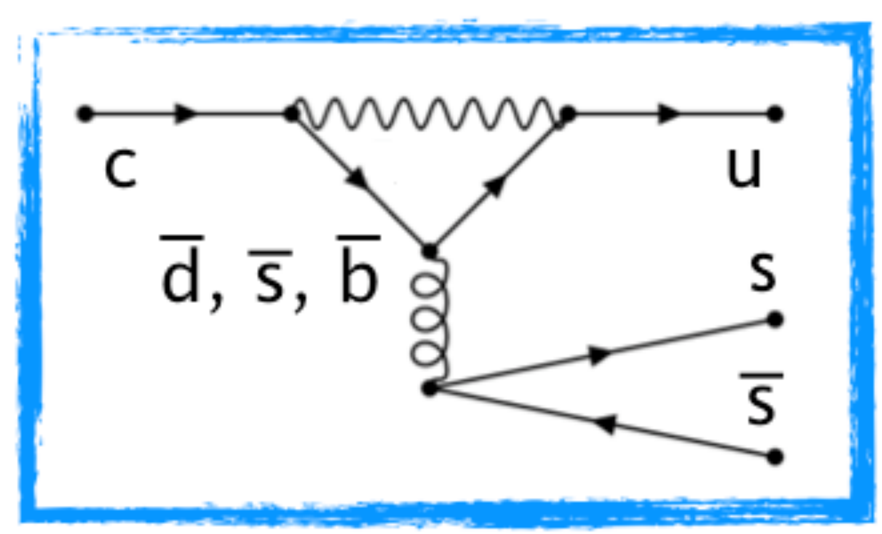
- Occurs if
- Corresponds to

$$\mathcal{A}_{CP} = \frac{|A_f|^2 - |\bar{A}_{\bar{f}}|^2}{|A_f|^2 + |\bar{A}_{\bar{f}}|^2} \neq 0$$

- Most promising channels are **Cabibbo-suppressed** (CS) decays because CPV may arise from the *interference* between the **tree** and the **penguin** amplitude

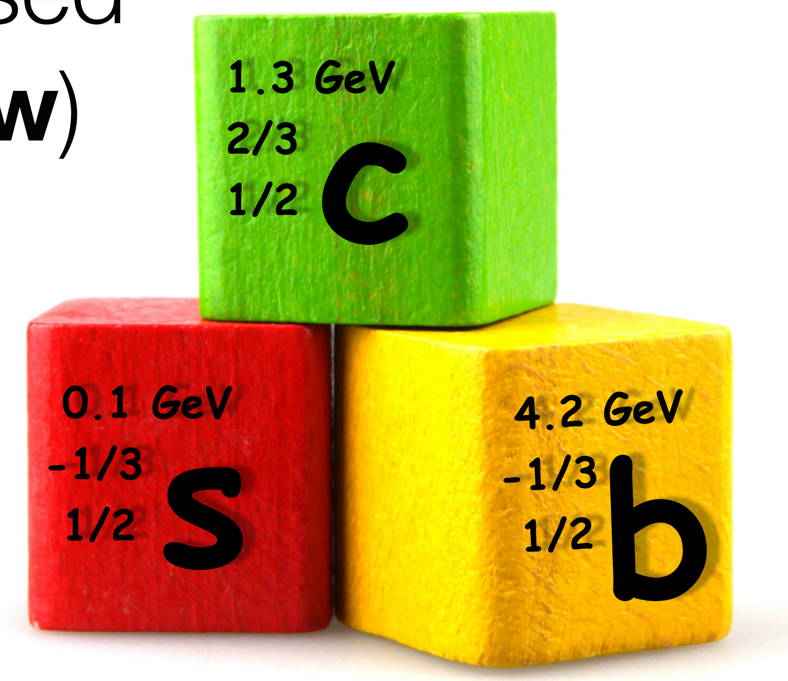


VS



Why charm is charming?

- *CP* violation (CPV) in **charm** is suppressed (*asymmetries* expected **~0.1% or below**)
  - *Sensitive* to possible contributions of **physics beyond the SM**
  - **Up-type** quark: complementary to studies in **K** and **B** systems



- ***LHCb*** is the main player in this quest

- CPV in charm has been searched for since decades, last year **finally observed** with the ΔA_{CP} measurement by the LHCb experiment!

[Phys. Rev. Lett. 122, 211803]

Search for CPV in $D^0 \to K^- K^+$ with Run-2 data

$$\boxed{\begin{aligned}\Delta A_{CP} &= A_{CP}(D^0 \to K^- K^+) - A_{CP}(D^0 \to \pi^- \pi^+) \\ &= (-15.4 \pm 2.9) \times 10^{-4}\end{aligned}}$$

- The measurement of $A_{CP}(D^0 \to K^- K^+)$ and $A_{CP}(D^0 \to \pi^- \pi^+)$ separately is necessary to understand the nature of the observed CPV

- Assuming U-spin symmetry one would *naively* expect $A_{CP}(D^0 \to K^- K^+) = - A_{CP}(D^0 \to \pi^- \pi^+)$ and thus $|A_{CP}(D^0 \to K^- K^+)| \sim 8 \times 10^{-4}$

- Last measurement of $A_{CP}(D^0 \to K^- K^+)$ from LHCb using Run-1 data:

$$A_{CP}(D^0 \to K^+ K^+) = \left[14 \pm 15 \text{ (stat)} \pm 10 \text{ (syst)}\right] \cdot 10^{-4}$$

[Phys. Lett. B 767 177-187]

- Expected uncertainty with Run-2 data: **8.5×10^{-4}**

[Physics case for an LHCb Upgrade II]

$$A(D \to f) = \frac{N(D\to f) - N(\bar{D}\to\bar{f})}{N(D\to f) + N(\bar{D}\to\bar{f})}$$

Strategy

- Prompt $D^0 \to K^-K^+$ from D^{*+} decays collected during Run-2
- Two methods to cancel nuisance asymmetries:
  - D^+ decays, same used in Run-1 analysis
  - D_s^+ decays, *new!* but already used in $A_D(K^-\pi^+)$ studies

particles with same color must have identical kinematic distributions

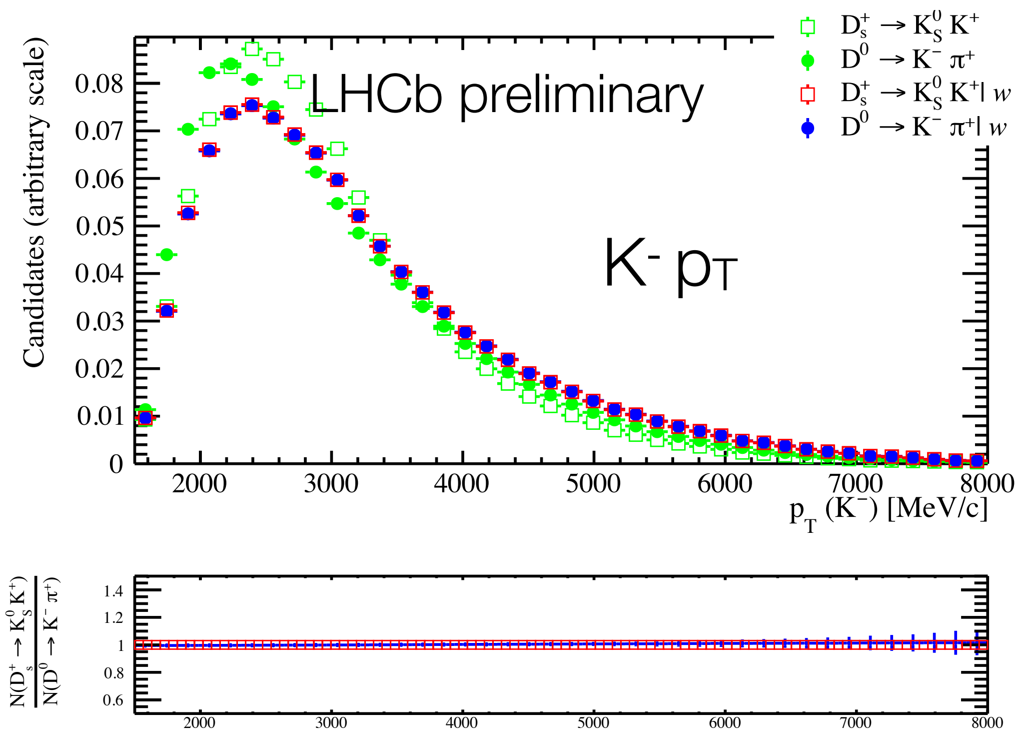
- Correct raw asymmetry *A* using *kinematically weighted* samples of Cabibbo-favored $D^0/D_{(s)}^+$ decays (where CPV can be neglected):

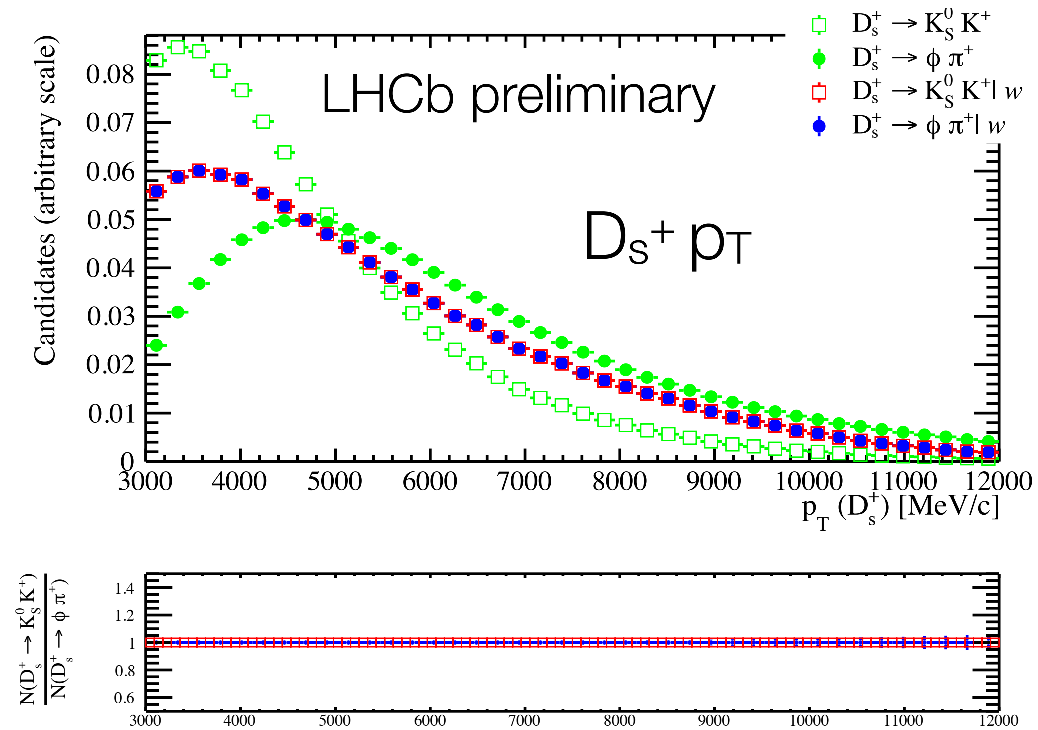
$$A_{CP}(D^0 \to K^-K^+) = +A(D^{*+} \to (D^0 \to K^-K^+)\,\pi^+_{soft}) - A(D^{*+} \to (D^0 \to K^-\pi^+)\,\pi^+_{soft})$$
$$+A(D^+ \to K^-\pi^+\pi^+) - \left[A(D^+ \to K^0_S\,\pi^+) - A_D(\overline{K}^0)\right]$$

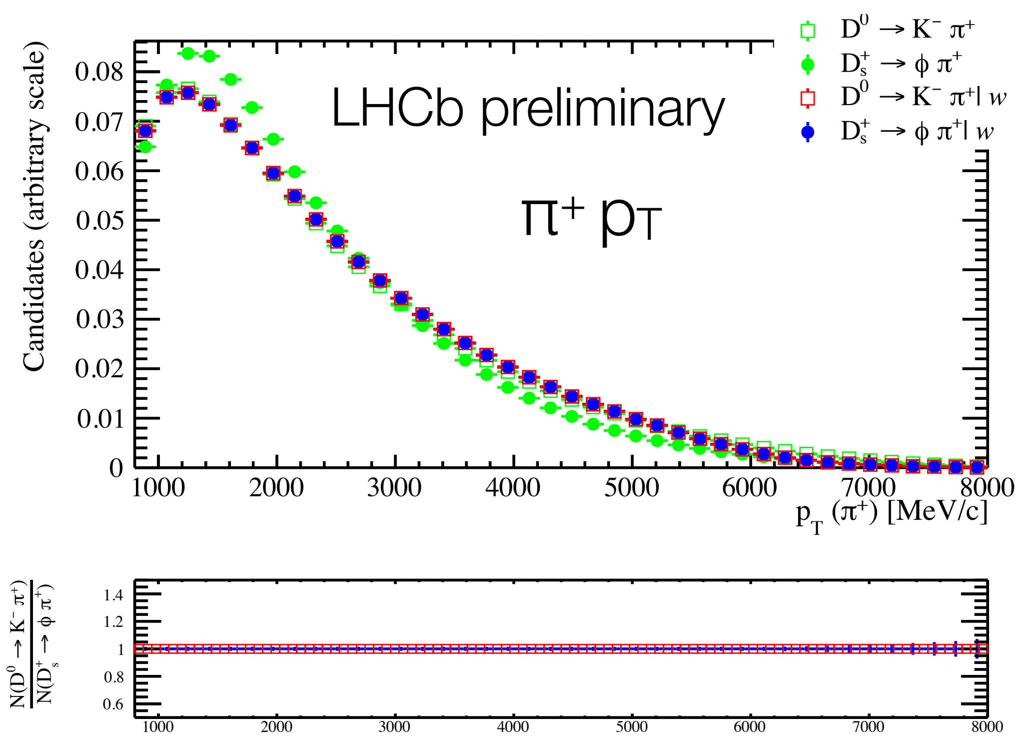
$$A_{CP}(D^0 \to K^-K^+) = +A(D^{*+} \to (D^0 \to K^-K^+)\,\pi^+_{soft}) - A(D^{*+} \to (D^0 \to K^-\pi^+)\,\pi^+_{soft})$$
$$+A(D_s^+ \to \phi\pi^+) - \left[A(D_s^+ \to K^0_S\,K^+) - A_D(\overline{K}^0)\right]$$

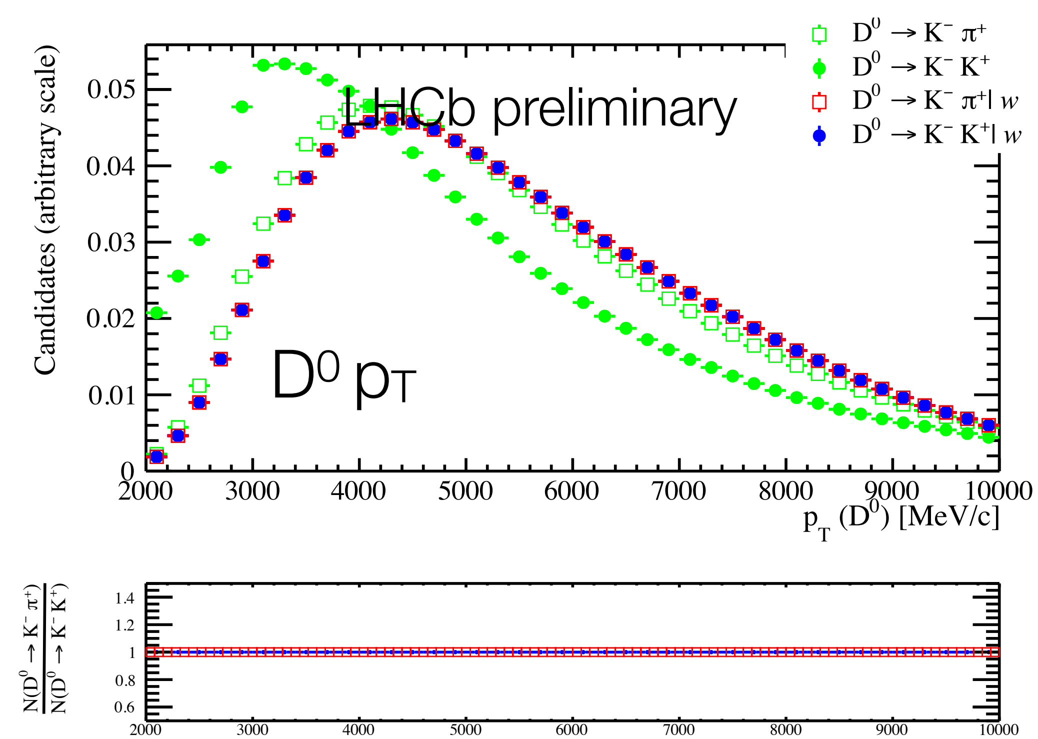
where $A_D(\bar{K}^0)$ is the detection asymmetry of neutral kaons, which includes mixing and CPV effects plots for D_S^+ method

BEFORE and AFTER kin. weighting





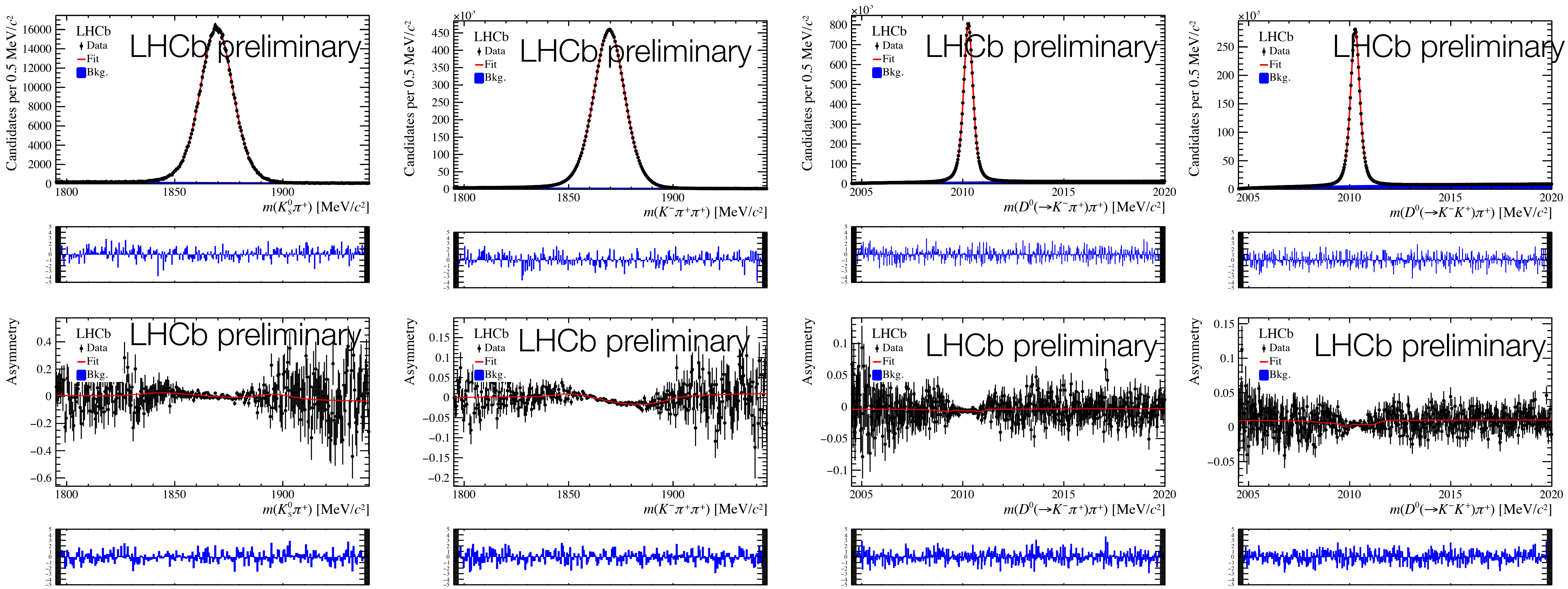




Fit results with D^+ method

$N_{effective} = \varepsilon_{kw} * N$

$D^+ \to K_S\pi^+$	$D^+ \to K^-\pi^+\pi^+$	$D^0 \to K^-\pi^+$	$D^0 \to K^-K^+$
N = ~6M	N = ~190M	N = ~120M	N = ~40M
ε_{kw} = ~25%	ε_{kw} = ~25%	ε_{kw} = ~35%	ε_{kw} = ~75%
$\sigma(A) = 8 \times 10^{-4}$	$\sigma(A) = 2 \times 10^{-4}$	$\sigma(A) = 2 \times 10^{-4}$	$\sigma(A) = 2 \times 10^{-4}$

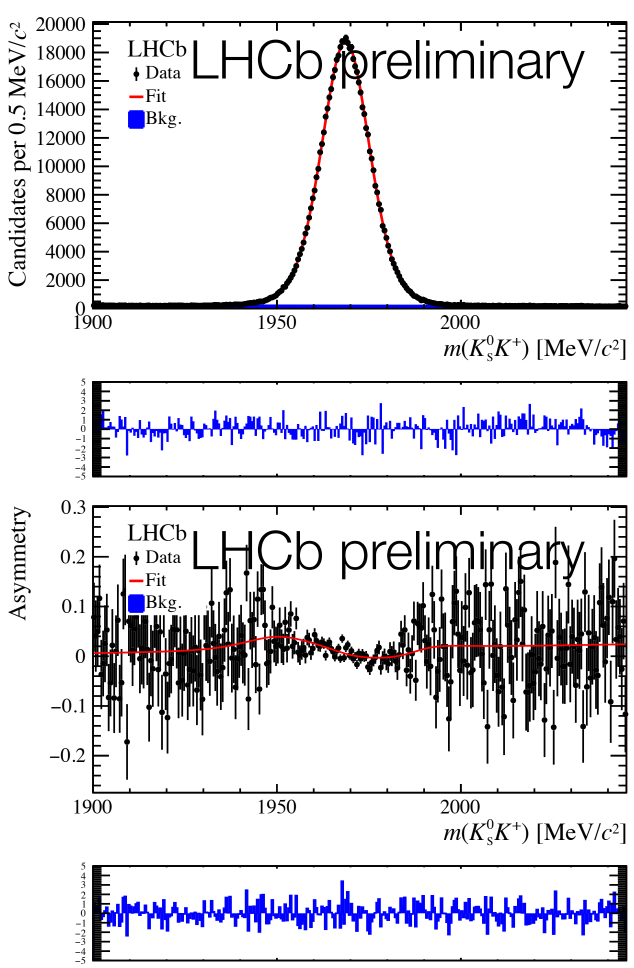


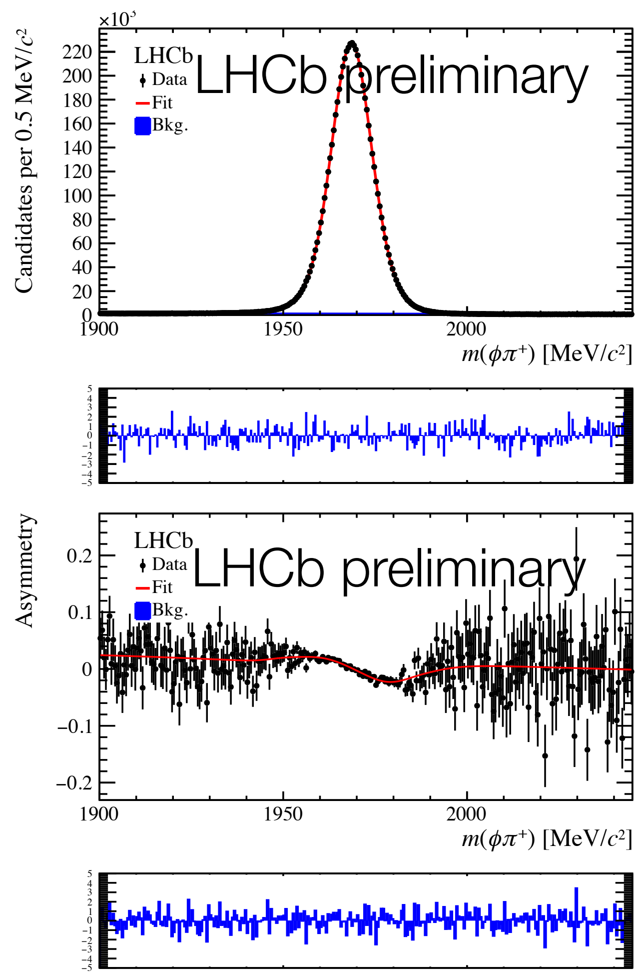
plots from 2016 MagDown sample only!

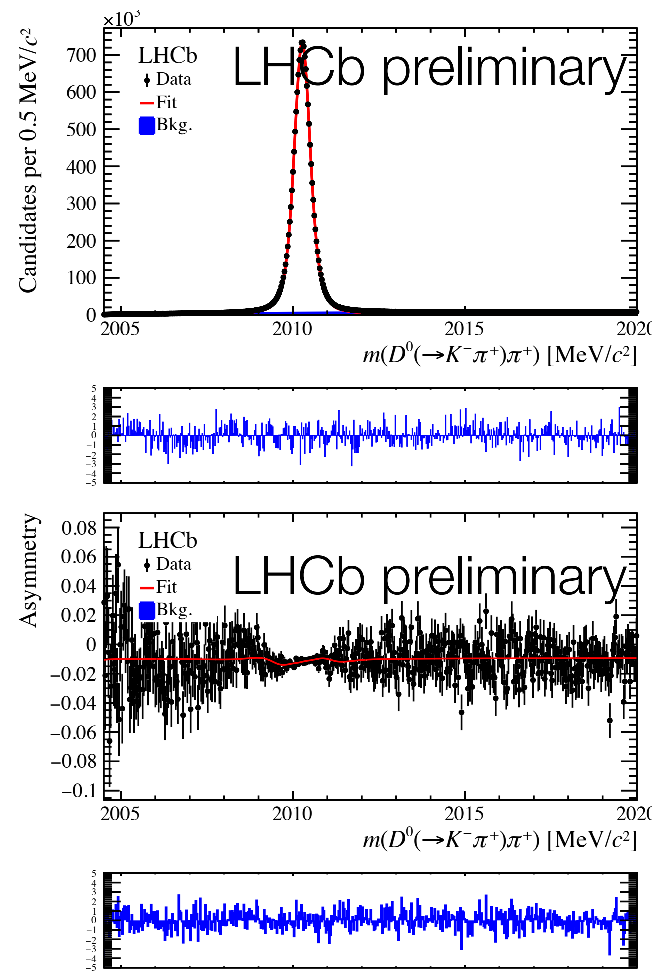
$N_{effective} = \varepsilon_{kw} * N$

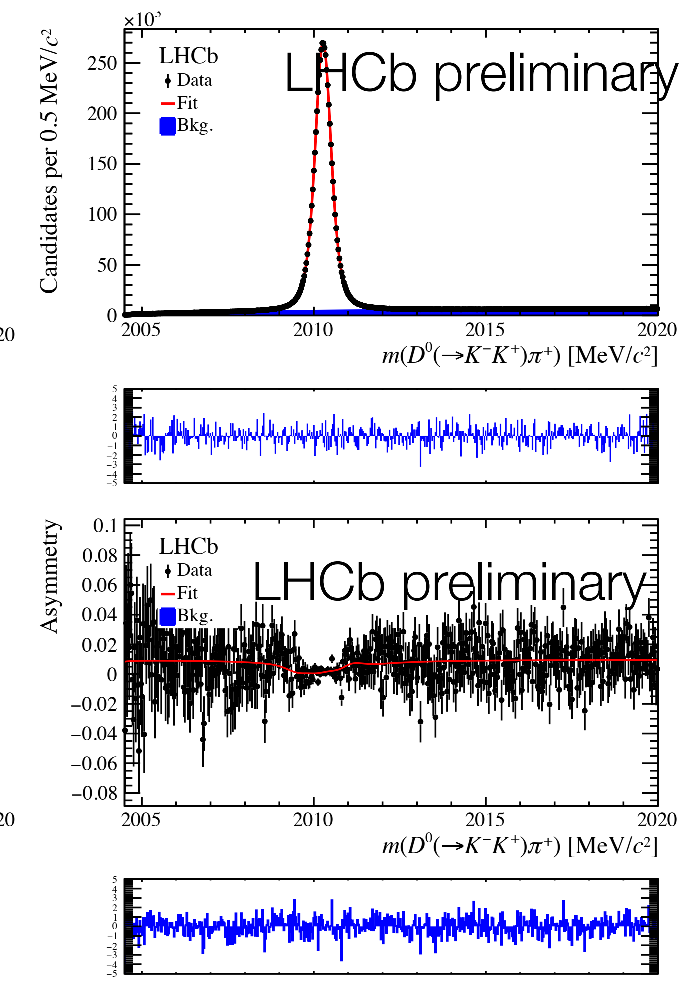
Fit results with D_s^+ method

$D_s^+ \to K_S K^+$	$D_s^+ \to \phi\pi^+$	$D^0 \to K^-\pi^+$	$D^0 \to K^-K^+$
N = ~5M	N = ~45M	N = ~110M	N = ~40M
ε_{kw} = ~70%	ε_{kw} = ~55%	ε_{kw} = ~75%	ε_{kw} = ~75%
σ(A) = 6x10^{-4}	σ(A) = 2x10^{-4}	σ(A) = 1x10^{-4}	σ(A) = 2x10^{-4}









plots from 2016 MagDown sample only!

Results and combination

- Following our recipes for $A_{CP}(D^0 \to K^- K^+)$:

$$A_{CP}^{blind}\,|\,D^+ = (56.6 \pm 8.7\ \text{(stat.)}\ ) \cdot 10^{-4} \qquad A_{CP}^{blind}\,|\,D_s^+ = (46.3 \pm 6.5\ \text{(stat.)}\ ) \cdot 10^{-4}$$

- The two values are compatible within 1 sigma
- The results have a *negligible* correlation, their combination gives

$$A_{CP}^{blind} = (50 \pm 5\ \text{(stat.)}\ ) \cdot 10^{-4}$$

Conclusions

- The measurement of $A_{CP}(D^0 \to K^-K^+)$ and $A_{CP}(D^0 \to \pi^-\pi^+)$ separately is necessary to understand the nature of the observed CPV
- A search for *CP* violation with *prompt* $D^0 \to K^-K^+$ decays collected during *Run-2* has been introduced and <u>preliminary</u> results have been presented
- A precision of 5×10^{-4} has been obtained combining D^+ and D_s^+ decays to cancel nuisance asymmetries (improvement of a factor 40% w.r.t. previous expectation)
- Hype for *Run-3*: with this improved strategy, we may be able to get an evidence for the single *CP* asymmetries in $D^0 \to K^-K^+$ or $D^0 \to \pi^-\pi^+$ in Run-3

Thanks!